Summary Statistics for Selenium in Vegetation Calculated from U.S. Geological Survey Data

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By T.F. Harms

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CONTENTS

FIGURES

TABLES

[Tables 3 and 4 follow references]

Summary Statistics for Selenium in Vegetation Calculated from U.S. Geological Survey Data

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ABSTRACT

Summary statistics for selenium in vegetation have been compiled from data generated by field studies conducted by the U.S. Geological Survey during the past 22 years. The data base contains approximately 6,000 analyses on about 150 species of plants and includes both cultivated crops and native species. Data were gathered both from studies designed to measure background or ordinary natural geochemical variations and from studies designed to measure the effects of potential point sources on local vegetation. The summary statistics presented here include means, deviations, and observed ranges, as well as references to published reports. The analyses of native vegetation should be of particular value because many studies of selenium in vegetation have focused more on species with agricultural importance.

INTRODUCTION

The Se content of vegetation has long been of interest, especially in the agricultural sector. Much of this interest stems from the element's role as an essential nutrient, as well as from its toxicity when present in excessive amounts. In the 1930's, selenium poisoning was identified as the cause of alkali disease that had plagued both the U.S. Army and settlers in the western South Dakota-eastern Wyoming region (Francke, 1934; Francke and others, 1934). Early interest focused on selenium's toxic potential, and it was not until 1957 that selenium was reported to be essential for animal health (Schwarz and Foltz, 1957). Combs and Combs (1986) estimated dietary requirements of 0.10 to 0.20 ppm Se to prevent such deficiency problems as white-muscle disease and reproductive failure. The effects of selenium toxicity appear when diets contain more than 3 to 8 ppm Se, depending somewhat on species and individual differences. Thus, a relatively narrow window exists between deficiency levels and toxicity: Symptoms of toxicity appear at 30 to 80 times deficiency levels. Although acute toxicity occurs from ingesting highly seleniferous plants containing hundreds to thousands of parts per million of selenium, the more common form of chronic toxicity comes from prolonged grazing on plants containing 5 to 20 ppm Se (James and others, 1991).

Several recent compilations of Se contents in plants have been made. Combs and Combs (1986) reported on the Se contents of grains, fruits, vegetables, nuts, and meats from about a dozen countries; they grouped data from the United States by their origin from areas with relatively low, moderate, and high soil Se contents. The excellent compilation by Ihnat (1989) contains chapters on the Se content of plants, foods, animal tissues, human tissues, geologic materials, freshwaters, marine environments, and the atmosphere, including an extensive listing of the concentrations in selenium-accumulator plants in a chapter on plants and agricultural materials. However, because most studies of selenium in vegetation have been agricultural or health based, fewer data are available on the Se contents of native or noncrop species.

In the 1950's and 1960's, selenium analyses by the U.S. Geological Survey generally were completed only to study its role as a pathfinder or indicator element in geobotanic prospecting for uranium deposits on the Colorado Plateaus or to characterize these deposits. Cannon (1964) extensively studied rock, soil, and plant relations around the uranium-vanadium deposits in the Yellow Cat area near Thompson, Utah. Selected samples were analyzed for selenium to investigate selenium-vanadium-uranium relations and to determine the feasibility of using selenium-accumulator plants as indicator plants in uranium prospecting. Listings of the presence of plant species both over and away from mineralized areas were developed to determine the tolerance of species to high levels of uranium. The selenium-accumulator plants *Astragalus pattersoni* and *A. preussi* proved to be excellent indicator plants for geobotanic prospecting for uranium-vanadium deposits. The analytical method that was used for Se determination involved distillation of selenium as the bromide and subsequent titration with sodium thiosulfate solution. This method of analysis is complex and requires a skilled operator, and so relatively few determinations were completed.

Beginning in the late 1960's, regional studies characterized by large numbers of samples were begun within the U.S. Geological Survey. Preliminary sampling for one of these studies (in Missouri) revealed that the distillation-titration method was not sensitive enough to measure the Se contents

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in these samples and that it was too laborious for the large number of samples which were to be collected. Instead, a fluorometric method was tested and accepted for use. During the past 22 years, U.S. Geological Survey laboratories have completed analyses for selenium on about 6,000 samples. About 22 percent of these data have never been published; the rest have been published in a wide variety of journals. A few of the studies that produced the data were specifically designed to determine Se contents; however, most were multielement biogeochemical studies in which selenium was included as one of several elements determined. Therefore, it is generally difficult to know that these selenium data are available. This report presents a compilation of the summary statistics for all species of plants for selenium determinations, both published and unpublished, that have been completed since 1970.

Regional biogeochemical studies by the U.S. Geological Survey, which began in the late 1960's, had as their primary purpose the description of typical or ordinary variations in natural-landscape units. The fundamental goal was to measure geochemical variation as it occurs in nature. Because these were to be unbiased estimates of relatively large areas, formal, objective sampling plans had to be designed that would maintain unbiased sampling while minimizing the number of samples to be collected, so that both fieldwork and analytical efforts could be reduced. Samples were submitted to the laboratories in random sequence to minimize the effects of analytical drift and operator bias by converting systemic errors in the laboratory to random errors. The results were interpreted by using statistical methods. In addition to regional studies, small-scale geochemical studies that centered on specific problems were conducted. In the Western United States, typically, these were studies of point-source emissions from the stacks of coal-fired electric-generating plants, or studies of the geochemistry of revegetated lands affected by surface mining of coal.

Various species of plants have been used in different parts of the United States for regional studies, and so baseline levels for Se contents have been developed for various plants. Sagebrush was used in the Western United States because sagebrush-grass vegetation constitutes one of the largest ecosystems in this region (Erdman, 1990). Trees and shrubs were used in Missouri, and small grains in the coal-bearing regions of the northern Great Plains. Data from all of these studies estimate the normal range of Se contents. For environmental surveys using plant geochemistry, these data provide a background against which immediate problems can be identified and against which potential long-term problems can be monitored. The data should also be useful in range and wildlife management. Many of the species listed in this report are browsed by wildlife. Shadscale and four-wing saltbush are listed as cool season browse for both livestock and deer in the *Range Plant Handbook* (U.S. Forest Service, 1937); willow and alder are important browse in Alaska.

Acknowledgments.—J.J. Connor, J.A. Erdman, B.M. Erickson, L.P. Gough, T.K. Hinkley, H.T. Shacklette, and H.A. Tourtelot all furnished unpublished data for inclusion in this report. Chemists who performed the fluorometric analyses of the plants were W.L. Cary, B.L. Bolton, M.A. Mast, and the author. P.L. Hageman and E.P. Welsch performed the hydride-generation/atomic-absorption-spectrometric analyses.

STUDY AREAS

The data in this report represent samples collected in the United States, with a few exceptions. A few lichen samples were collected in Great Britain by H.T. Shacklette, and some samples of wheat, oats, and barley were collected in southern Saskatchewan, Canada, by J.A. Erdman. Although samples from all regions of the United States are part of the data base, the data presented here are heavily weighted by samples collected in the west half of the United States and specific areas within the West.

Most samples were collected during studies conducted under six major projects: geochemistry of Missouri, geochemistry of foods, geologic studies of the Western energy regions, geochemistry of Alaska, geologic studies of the Challis, Idaho, 1:250,000-scale quadrangle, and U.S. Department of the Interior irrigation-drainage studies. Each of these projects is described briefly below.

MISSOURI

The Missouri study was a multidisciplinary project in cooperation with the Environmental Health Surveillance Center of the University of Missouri; it was designed to investigate geochemical and health-disease relations throughout Missouri. The U.S. Geological Survey conducted an assessment of the geochemical variations of rocks, soils, waters, and vegetation across broad, geologically diverse subdivisions of the State. For first-phase, reconnaissance geochemical studies of vegetation, the State was divided into six areas on the basis of potential climax vegetation (fig. 1). One species, smooth sumac, was collected in all six areas to measure biogeochemical variation throughout the State; a second species, buckbush, was collected in five areas but, because of limited availability, at only a few sites in the sixth area. In addition to sumac and buckbush, samples of one or more species of trees representative of each area were collected to estimate the species variation within each area and to determine the geochemical characteristics of each species. Corn and soybeans were collected as the crop plants from four of the six areas. Associated soils were collected at each vegetation site to investigate plant-soil relations. Formal sampling plans in the field and strict randomization procedures in the laboratories were used to ensure the reliability of the data. Results from a geochemical survey of the vegetation were reported by Erdman and others (1976a, b).

FOODS

The foods study assessed regional patterns in the chemical-element contents of fresh produce. Fruits and vegetables were collected from 11 areas of commercial production scattered across the United States. The objectives of this study were to evaluate the concentrations of elements with nutritional or environmental significance that occur in fruits and vegetables entering commercial channels, and to provide baseline or background levels of elements in the edible portions of fruits and vegetables as they are commercially grown in the United States. The study was designed to permit comparisons among the types of produce, areas of production, and fields within an area. Produce was collected from 11 counties in 10 different States; 2 counties in California were sampled. Counties were chosen as the largest sampling unit because crop-production records are kept at this level. From 2 to 12 types of produce were sampled at each area; each individual type was sampled in one to five areas. Duplicate samples were collected at 45 sites to measure sampling variance; analytical variance in the laboratory was measured by splitting 45 randomly selected samples. The samples of fruits and vegetables were collected from plants in the fields shortly before the crops were harvested. In the Northern States, produce was collected before the fall harvest; in the Southern States, winter produce was collected. The samples were prepared as for eating (washed, peeled, and so on) and then dried. Cultivars are not necessarily the same from each area because

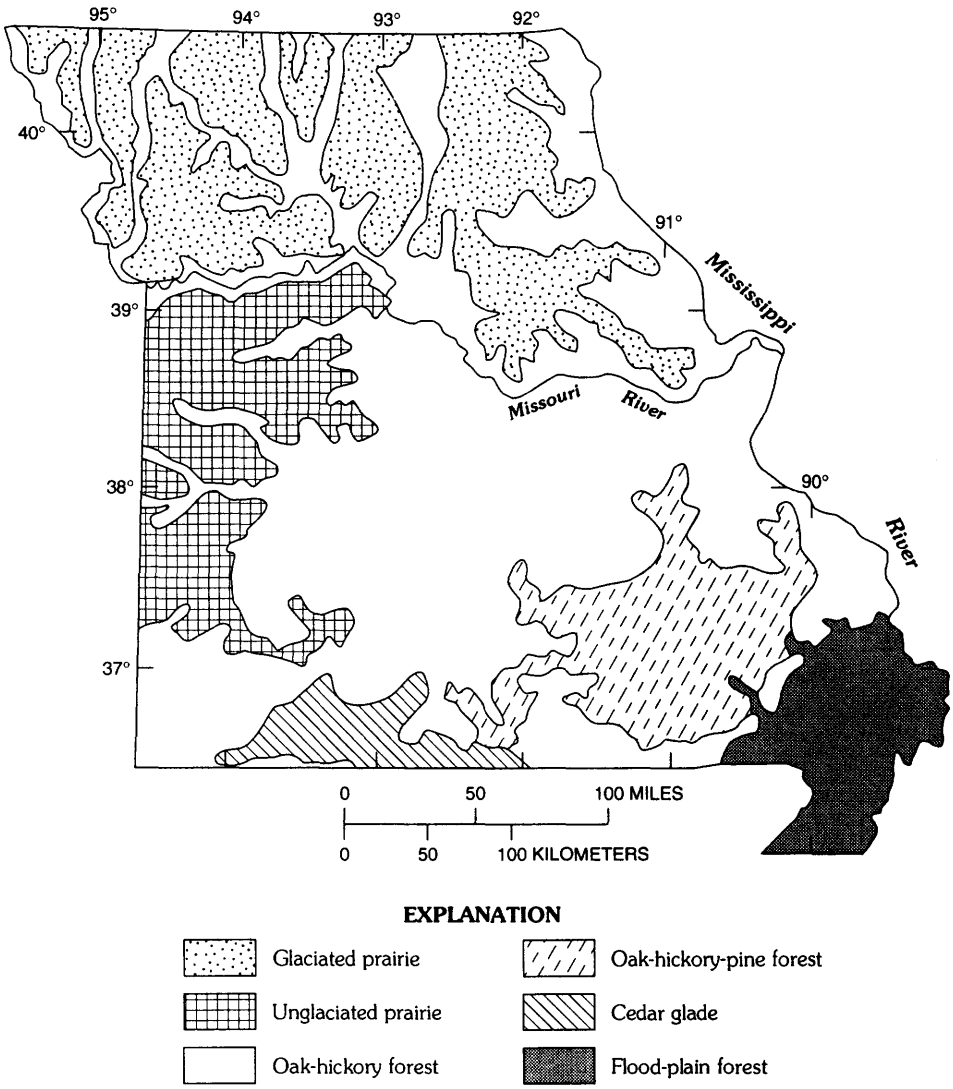

Figure 1. Missouri, showing areas of major vegetation types. Modified from Erdman and others (1976b).

they are adapted for specific regions of the country, but all were commercial varieties. The results were reported by Shacklette (1980).

One of the counties selected for sampling in the foods study was Yakima County, Wash., where apples, pears, peaches, grapes, plums, tomatoes, and potatoes were collected. During the 1980 eruption of Mount St. Helens, volcanic ash fell in this area. In September 1980, the same types of produce were collected again, from the same farms and fields when possible. The results were reported by Gough and others (1986).

WESTERN ENERGY REGIONS

A large group of studies were designed to investigate the geochemistry of rocks, soils, plants, and waters at sites overlying major coal and oil-shale resources in the northern Great Plains and Rocky Mountain regions. Included in this group are baseline studies to determine the natural geochemical variations in materials in the region, as well as small-scale studies of the geochemistry of materials at existing coal mines and coal-fired electric-generating plants.

Studies designed solely to estimate baseline values applicable to these regions include those on (1) sagebrush in eight western physiographic provinces (fig. 2); (2) grass, sagebrush, and lichen in the Powder River Basin (fig. 3); (3) grasses and four-winged saltbush in the San Juan Basin (fig. 3); and (4) various small grains in the northern Great Plains (fig. 3). The regional sagebrush study was designed to estimate the variations in elemental concentrations at geographic distances of from 0.1 to more than 200 km, as well as the variations in elemental concentration that are characteristic of sagebrush throughout the various provinces. In the northern Great Plains, where small-grain production is important agriculturally, baseline values have been derived for oats, barley, hard red spring wheat, hard red winter wheat, and durum wheat. Baseline values obtained from all of these studies were used to assess the possible effects from existing coal mines and coal-fired electric-generating plants.

The geochemical effects of land-surface disturbance, stack emissions, fly ash, and so on were measured, and the probable effects of future operations were estimated from studies at representative areas where coal mines and powerplants currently operate. The effects of stack emissions at several powerplants were studied by using lichens, sagebrush, and Indian ricegrass to determine whether measurable changes in the local environments could be attributed to the presence of

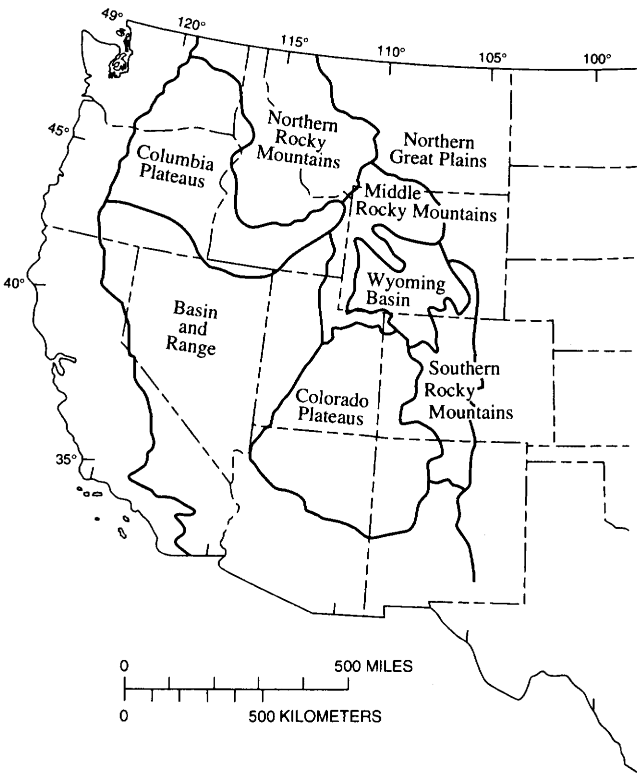

Figure 2. Western United States, showing physiographic provinces sampled during a regional baseline study of big sagebrush. Modified from Ebens and Shacklette (1982).

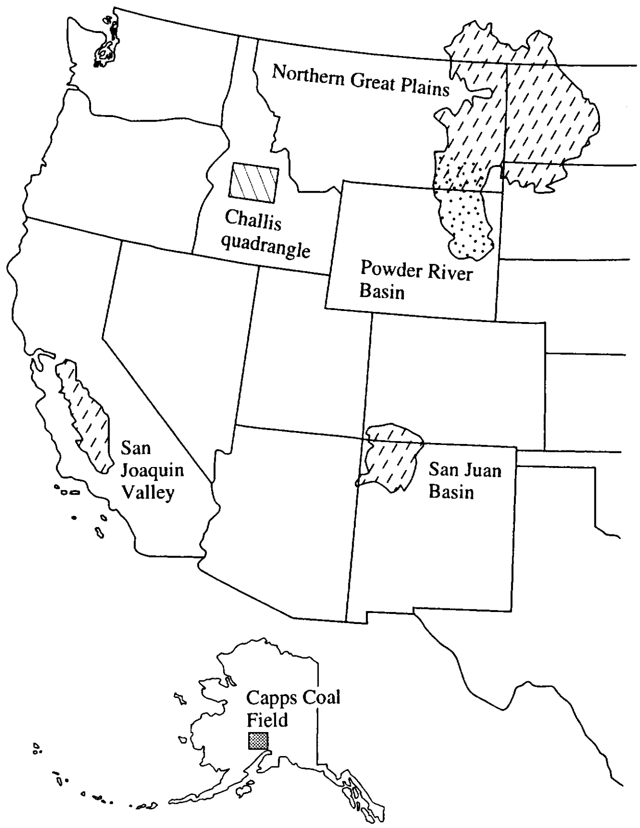

Figure 3. Western United States, showing locations of the Challis 1°-by-2° quadrangle, San Joaquin Valley, and selected parts of western energy regions (Powder River Basin, northern Great Plains, and San Juan Basin). Inset map of Alaska shows location of the Capps Coal Field. Same scale as in figure 2.

the powerplants. Regulations governing the reclamation of surface coal mines require that the surface be restored to its original contours to an acceptable degree and revegetated. At mines where spoil material had been covered or mixed with topsoil and revegetated, studies compared both native and crop species growing on the rehabilitated sites and adjacent undisturbed areas to assess the effects of reclaimed spoils on elemental concentrations in plants. Alfalfa, wheat, four-winged saltbush, sweetclover, and several species of wheatgrass have all been collected for mine-rehabilitation studies.

All of these studies followed well-designed sampling plans to identify the plants of interest and reduce sampling and analytical bias; the results were interpreted by using statistical techniques. Many of these studies, along with the data collected, were summarized by Ebens and Shacklette (1982).

ALASKA

The main objectives of the Alaska study were to estimate a central tendency and typical ranges for elemental concentrations in soils throughout the State and to make broad-scale concentration maps for several chemical elements in the soils (Gough and others, 1988). Although the major emphasis of this study was on the chemical characterization of soils, a plant sample was also collected at most sites. The sample sites were selected as representative of the typical landscape of Alaska in that particular area. Areas of known mineralization or contamination were avoided, and the samples were collected 100 m from the nearest road to avoid roadside contamination. Because only the dominant vascular plant species was collected at each site, trees were sampled most frequently, followed by woody shrubs. Although the samples were collected over several years (partly by volunteer efforts of U.S. Geological Survey personnel as they traveled to field camps), the samples were analyzed as a single suite after all collecting had been completed. The data for plant samples were reported by Gough and others (1991).

CHALLIS, IDAHO

The Challis, Idaho, 1:250,000-scale quadrangle (1°-by-2° sheet) (fig. 3) is part of an ongoing U.S. Geological Survey program to conduct mineral-resource assessments in selected 1:250,000-scale quadrangles throughout the United States. Geologic, geochemical, and geophysical investigations are conducted in each quadrangle. Biogeochemical studies, in addition to the more common stream-sediment sampling, were included in the study of the Challis quadrangle. The plants analyzed for selenium were commonly collected as preliminary "grab" samples to evaluate several species for their usefulness in biogeochemical exploration in the area, or were collected on traverses across faults or geologic units to study potential mineralization associated with the fault zone or geologic formation. Although selenium was not the metallic element of economic interest, it was determined to assess its usefulness as a pathfinder or indicator element for uranium, gold, and molybdenum deposits. Se contents were generally low and fairly uniform, and so its usefulness as an indicator element was limited; selenium determinations were dropped as the studies progressed. Although none of the selenium results have been published, preliminary results from all facets of the investigations of the Challis quadrangle were presented at the Northwest Mining Association convention in Spokane, Wash., on December 1–2, 1983 (McIntyre, 1985).

U.S. DEPARTMENT OF THE INTERIOR'S IRRIGATION-DRAINAGE PROGRAM

In response to congressional concern about the quality of drainage water in Federally funded irrigation projects, the U.S. Department of the Interior formed a multiagency workgroup (U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, and U.S. Geological Survey) in 1985 to investigate the potential for damage to affected lands. The objective of these investigations is to determine whether irrigation practices may be harmful to human health, wildlife, fish, or other water users, or reduce water quality for beneficial uses. Field-screening studies of selected areas utilize limited sampling of water, sediment, and wildlife. The samples are analyzed by using multielement analytical techniques to screen areas for excessive amounts of metals. These studies are followed by more detailed investigations in areas deemed appropriate on the basis of anomalous concentrations of trace elements found during screening studies. Both sagebrush and alfalfa were included in detailed biogeochemical studies in the Kendrick Reclamation Project area, Natrona County, Wyo. (See and others, 1992), and alfalfa was used in followup studies in the Uncompahgre Reclamation Project area, Delta and Montrose Counties, Colo. (Crock and others, 1994). In each of these areas, samples of sagebrush (Kendrick) or alfalfa (Uncompahgre) growing on soils derived from specific geologic units were collected to assess the importance of each unit as a source of selenium in the area.

LABORATORY METHODS

All selenium analyses were completed on dried vegetation. Drying provided several advantages: It stopped the growth of bacteria, provided a sample that was easily stored, and provided a stable sample for weighing without the problems present in homogenized wet tissues. In studies of the losses of selenium during heated drying by Palmer and Olson (1991), samples of Astragalus lost 0 to 5 percent of their Se content when heated at 75°C for 22 hours (Se content, >600 ppm), whereas grains showed only small losses even when heated at 105°C (Se content, >10 ppm). Erdman and others

(1989) found no significant loss of selenium in alfalfa (Se content, <1 ppm) when dried by (1) oven heating in forced air at 100°C for 90 minutes followed by heating at 65°C for 30 hours, (2) microwave heating for 15 minutes, or (3) freeze-drying.

Washed (if this was part of the study design) and unwashed samples were airdried or dried in an oven at 40°C for 1 to 2 days until the material was brittle. After drying, the samples were pulverized in Wiley or Christie-Norris mills, using 10-mesh (2 mm) or finer screens to control the particle size of the ground sample. Samples that were to be divided into two fractions for use as analytical duplicates were split after grinding by using a Jones splitter.

Almost all the plant samples were analyzed by using a fluorometric method; the other samples were determined by using hydride-generation/atomic-absorption spectroscopy. The fluorometric method has been widely used for plants and many other types of material since the late 1960's. The 14th edition of the methods handbook of the Association of Official Analytical Chemists still uses fluorometric methods as the official methods for selenium determination in foods and plants (Williams, 1984). A brief description of this method as used by the U.S. Geological Survey is given below.

At least 1 g of dried, ground vegetation was digested in nitric and perchloric acids; hydrogen peroxide was used to help break down resistant oils and waxes. The selenium in solution was complexed with 2,3–diaminonaphthalene to produce 4,5–benzopiazselenol; this complex fluoresces in proportion to its Se content. The selenium complex was extracted into cyclohexane both to isolate it and to improve the analytical sensitivity. The fluorescence was measured at 525 nm and the result compared with those produced by standards taken throughout the entire procedure (Harms and Ward, 1975). The lower limit of determination is 0.01 ppm Se for a 1-g sample; such samples as food plants containing less than 0.01 ppm Se were analyzed by using 2 g or more of sample.

Partly because the method was sensitive and worked well, and partly because U.S. Geological Survey botanists-geochemists wanted to maintain continuity of analytical methods between projects so that selenium values were directly comparable among studies, this method was used until 1989, when it was replaced by hydride-generation/atomic-absorption spectroscopy using an automated, continuous-flow system. The digestion procedure remained the same as for the fluorometric method, using nitric and perchloric acids to destroy the sample matrix. The selenium in the sample solution was reacted with sodium borohydride to form gaseous hydrogen selenide (H_2Se), which was swept into a heated quartz furnace on an atomic-absorption spectrometer. The Se content was determined from an aqueous standard calibration curve (Crock and Lichte, 1982; Sanzolone and Chao, 1987).

Two suites of the sample data in this report were determined by using this procedure: alfalfa from the Uncompahgre Reclamation Project area, Delta and Montrose Counties, Colo., and wheat from the San Joaquin Valley, Calif. All other results were obtained by using the fluorometric method. Some analytical bias may exist between these two suites of samples and the rest of the data because two different methods were used to determine Se content. Even within the data obtained from fluorometric analyses, slight modifications to the method over the years, differing batches of chemical reagents, and different operators may have introduced minor biases.

Table 1. Se contents of standard reference materials.

[All values in parts per million dry weight, determined by fluorometry. NIST, U.S. National Institute of Standards and Technology; USGS, U.S. Geological Survey. n.d., not determined]

NIST standard reference material		NIST-certified value	Gladney (1980)	USGS value
No.	Name			
1567	Wheat flour	1.1±0.2	1.12±0.01	0.97, 0.99
1570	Spinach	n.d.	[1].039±0.015	.032
1571	Orchard leaves	.08±0.01	[2].08±0.009	.075
1572	Citrus leaves	[3].025	n.d.	[4].037±0.004
1575	Pine needles	n.d.	[5].049±0.004	.056

[1]Based on 7 analyses.
[2]Based on 36 analyses.
[3]Uncertified value.
[4]Based on 6 analyses.
[5]Based on 3 analyses.

QUALITY CONTROL

Botanic standard reference materials from the U.S. National Institute of Standards and Technology (NIST; formerly the U.S. National Bureau of Standards) have been purchased and analyzed for selenium to assess the accuracy of our analyses as the standards have become available, beginning with the original botanic material, orchard leaves, issued in 1971. Gladney (1980) compiled the results of analyses of standard reference materials from articles published between 1972 and 1980 in 15 chemistry and geochemistry journals. Most of these results were generated by neutron-activation analyses, although other analytical methods also were included. From the original data in these articles, Gladney computed the mean $\pm 1\sigma$ for chemical elements in 16 biologic and environmental standard reference materials. The close agreement among the NIST-certified values, the values calculated by Gladney, and the values determined by the U.S. Geological Survey on five botanic standard reference standards are listed in table 1.

Statistical techniques were used to assess the precision of selenium determinations. In most studies, 5 to 10 percent of the samples were selected to be split into two parts to obtain duplicate analyses of the sample. The samples from the study area plus the sample splits were arranged and analyzed in an order that was random as to both plant species (for sample sets with mixed species) and geographic location.

Table 2. Geometric errors associated with regional background studies.

Project	Geometric error
Missouri:	
Native species	1.22
Crop species	1.09
Foods	1.24
Western energy regions:	
Sagebrush, Powder River Basin	1.13
Sagebrush, regional study:	
Columbia Plateaus, Colorado Plateaus, Basin and Range.	1.23
Rocky Mountain provinces, Wyoming Basin.	1.37
Lichen, Powder River Basin	1.07
Galleta, San Juan Basin	1.05
Snakeweed, San Juan Basin	1.06
Wheat, hard red spring	1.11
Wheat, hard red winter	1.09
Wheat, durum	1.12
Barley	1.09
Oats	1.05

The analytical variance was estimated from these sample splits by using the equation

$$s_a^2 = \frac{\sum_{i=1}^{n}(X_{1i} - X_{2i})^2}{2n},$$

where s_a^2 is the error variance, X_{1i} and X_{2i} are the Se contents (or their logarithms) in the two splits of the ith sample, and n is the number of samples that were split. The standard error is the square root of the variance. If the variance has been estimated from logarithmic data, the square root is the logarithmic standard error, and the geometric error is the antilogarithm. For example, for native plants from Missouri, the variance attributed to laboratory procedures was 0.00687, on the basis of results from 50 pairs of samples (Erdman and others, 1976b), the logarithmic standard error was 0.08289, and the geometric error was 1.22. The geometric error gives confidence levels about the geometric mean. The analytical method is reproducible within a factor of the error (for Missouri, 1.22) at the 68-percent-confidence level and within a factor of the square of the error ($1.49=(1.22)^2$) at the 95-percent-confidence level (Miesch, 1976).

Geometric errors for several studies are listed in table 2; the relatively small errors indicate that the data should be quite reproducible. For suites of data with large numbers of samples, such as the native species in Missouri (n=950) and the foods study (n=665), the analytical variance is a composite estimate across plant species and areas. This estimate was made both for economic reasons and because the analytical variance was not expected to differ across areas or sample types.

ANALYTICAL SENSITIVITY

Every analytical method has both upper and lower limits of sensitivity beyond which it is ineffective. The upper limit can be extended either by decreasing the sample weight (within bounds that allow for accurate weighing and adequate subsampling of the material) or by diluting the sample solution and using only an fraction of it. This second procedure was the one normally used for samples with high Se contents. Although these procedures extend the upper limit, they are detrimental to the precision of the analysis because extra steps (each with its own error), multiplication factors, or both are introduced into the procedure.

Very little can be done to improve the lower limit of sensitivity beyond increasing the sample weight. Thus, because of insufficient analytical sensitivity, Se contents may be reported as less than some specified lower limit; these values are said to be "censored" or "qualified." For studies that contain censored data, the geometric mean and geometric deviation were estimated by using the technique of Cohen (1959), as described by Miesch (1967). This technique includes all the data in the calculation of the mean, not just the uncensored data, and involves an adjustment of the summary statistics that have been computed for the uncensored data. In some studies, censoring is so severe (about half the data are censored) that such an adjustment is impossible or its results are questionable.

The use of Cohen's (1959) technique to estimate the geometric mean can lead to values that are below the limit of determination. For example, the range of Se content in pears from Wayne County, N.Y., that were collected as part of the foods study is from less than 0.005 to 0.02 ppm. The geometric mean, as calculated by Cohen's procedure, is 0.0048 ppm.

The statistical summaries presented here are accompanied by an indication of the degree to which the raw data are censored. For this purpose, a detection ratio is used, which is a fraction in which the numerator is the number of samples with uncensored values and the denominator is the total number of samples. The difference between the two numbers is the number of samples with censored values in the data set. For example, the detection ratio for the pears from New York is 7:10; that is, 10 samples of pears, of which 7 samples had Se contents of at least 0.005 ppm or more and 3 samples had censored Se contents of less than 0.005 ppm. The detection ratio for alfalfa samples from the Kendrick Reclamation Project is 112:112 because all the measured values are greater than the lower limit of sensitivity (112 valid numbers, 112 samples).

DATA TRANSFORMATIONS

Frequency distributions for chemical elements in most geochemical studies are not normal (Gaussian) distributions. More commonly, they are asymmetric with a long tail toward high values (positive skewness), especially for minor or trace elements. For data that are unimodal and positively skewed, a transformation to logarithms (base 10) will result in a distribution that is closer to normal form, although even a frequency distribution of logarithmic data may show positive or negative skewness (Miesch, 1967).

Data from the analyses of 69 samples of hard red spring wheat from the northern Great Plains illustrate this trend. These samples were collected as part of a regional baseline study for grains, from storage bins on farms in North Dakota, South Dakota, Montana, and Saskatchewan, Canada, using a 6-ft-long grain probe to provide a composite sample of grain that had been harvested from many acres (Erdman and Gough, 1978). Se contents in these samples range from 0.15 to 2.2 ppm. A frequency diagram of the original data (fig. 4*A*) exhibits a clear positive skewness, with a tail of data toward the right. Converting these data to logarithms and using the same class intervals as in the original data set results in frequency diagram (fig. 4*B*) that is closer to a normal distribution.

The best measure of the central tendency of data with a log-normal distribution is not the arithmetic mean but the geometric mean, which is the antilogarithm of the mean of the logarithmic data. The calculations used to determine the geometric mean (GM) are summarized by the equations

$$x = \log_{10} y,$$

$$\bar{x} = \frac{\sum_{i=1}^{n} x}{n},$$

and $$GM = 10^{\bar{x}}.$$

For the 69 samples of wheat, the geometric mean is 0.64 ppm, the median is 0.60 ppm, and the arithmetic mean is 0.76 ppm. For log-normal distributions, the geometric mean will be closer to the median than the arithmetic mean, which in these distributions overestimates the median. If the distribution were symmetrical on a logarithmic scale, then the geometric mean would be the same as the median.

A measure of the scatter or variation to be expected about the mean is given by the geometric deviation (GD), which is the antilogarithm of the standard deviation of the logarithmic data; it is calculated similarly to the geometric mean by first converting the data to logarithms. As with the standard deviation in a normal distribution, about 68 percent of the samples in a randomly selected suite with a log-normal distribution is estimated to fall between GM÷GD and GM×GD, about 95 percent between $GM \div (GD)^2$ and $GM \times (GD)^2$, and 99.7 percent between $GM \div (GD)^3$ and $GM \times (GD)^3$. The wheat samples in the example above have a geometric mean of 0.64 ppm and a geometric deviation of 1.85. Thus, for a randomly selected suite of samples of hard red spring wheat from the northern Great Plains, the typical or most common Se content is 0.64 ppm. Approximately 68 percent of the samples should contain from 0.35 to 1.18 ppm Se, about 95 percent from 0.19 to 2.19 ppm Se, and more than 99 percent from 0.10 to 4.05 ppm Se.

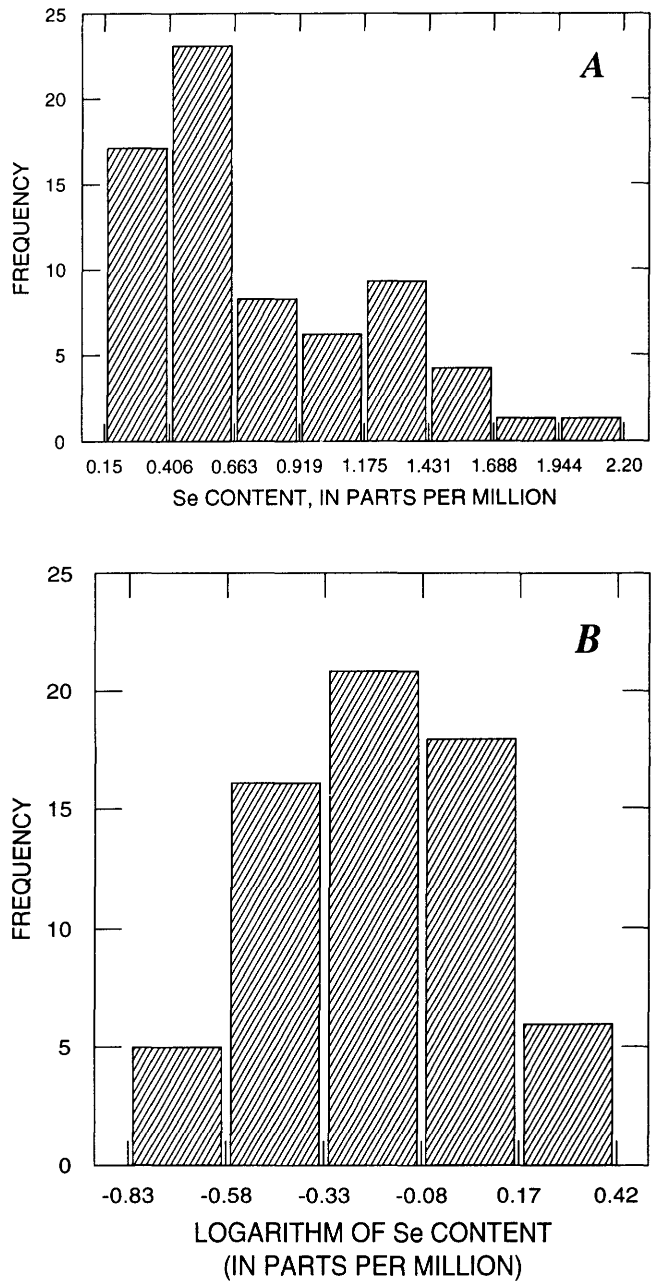

Figure 4. Frequency distributions of Se content (*A*) and logarithm of Se content (*B*) in hard red spring wheat.

The central 95-percent range that is created from an unbiased sample set by calculating GM÷(GD)^2 and GM×(GD)^2 has been proposed as a "baseline" range to be used to define typical or commonly expected Se contents (Ebens and others, 1973; Tidball and Ebens, 1976). Se contents outside this range would be viewed as uncommon, outliers, or anomalous. Such Se contents need not reflect metal deficiency or pollution, but they would be worthy of further investigation. This range was arbitrarily chosen because, owing to chance alone, only 5 percent of all samples reflecting natural conditions would fall outside it. For example, any Se content above the upper limit of the central 95-percent range has only 2$^1/_2$ chances in 100 of reflecting natural variation in the material within the study area. The central 99.7-percent range also could be used to define anomalous values if a greater degree of certainty would be needed to judge a value anomalous.

DESCRIPTION OF DATA TABLES

The geochemical summaries from selenium analyses are listed in tables 3 and 4: The data on cultivated (agricultural) crops, such as alfalfa and tomatoes, followed by those for grains, vegetables, and fruits, are listed in table 3, and the data on native species in table 4. The plants in table 4 are grouped into broad categories of lichens, grasses, shrubs and herbs, and trees. Within these categories plants are grouped by families. Each plant species is identified by its common name, followed by the scientific name. Locations are listed by State and county except for studies of larger physiographic provinces; approximate boundaries for these areas are shown in figures 1 through 3. Each entry in tables 3 and 4 also identifies the part of the plant that was sampled, because this item influences the data obtained. The rest of tables 3 and 4 contain the following information: the geometric mean, which estimates the most probable Se content to be expected in the material; the geometric deviation, which estimates the magnitude of scatter in the data; the range of values observed in each sample suite; and finally, a reference to a published report. The geometric means and observed ranges are all listed in parts per million (ppm) dry weight (10^{-4} weight percent); the geometric deviation is a factor and has no unit of measure.

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TABLES 3, 4

Table 3. Se contents of agricultural crops.

[All values in parts per million dry weight. Detection ratio is a fraction in which the numerator is the number of samples with uncensored values and the denominator is the total number of samples. GD, geometric deviation; GM, geometric mean. Do., ditto]

Species sampled	Plant part sampled	Detection ratio	GM	GD	Observed range	Reference
Alfalfa (*Medicago sativa*):						
California: San Joaquin Valley	Leaves and stems, washed	49:49	0.37	2.05	0.04–1.1	Severson and others (1991).
Colorado: Jefferson County	Leaves and stems	3:3	.093	2.24	.04–0.20	H.A. Tourtelot (unpub. data, 1978).
Montana: Rosebud, Richland, and Big Horn Counties	Leaves and stems, washed	5:5	.12	3.25	.03–0.65	Gough and Severson (1981b).
North Dakota: Ward, Oliver, and Stark Counties	do	11:11	.50	1.65	.15–0.90	Do.
Wyoming: Natrona County, Kendrick Reclamation Area	do	112:112	.98	3.27	.10–40	See and others (1992).
<u>Collected in association with coal-mine studies:</u>						
Colorado: Routt County, Energy Fuels Mine	Stems, leaves, fruit, washed	10:10	.39	1.81	.20–1.4	Gough and Severson (1981b).
Seneca No. 2 Mine	do	10:10	.32	2.06	.10–0.90	Do.
Montana: Richland County, Savage Mine	Terminal 10–15 cm (stems, leaves)	3:3	1.1	2.09	.75–2.7	Ebens and Shacklette (1982).
Rosebud County, Big Sky Mine	do	3:3	.22	2.13	.10–0.45	Do.
Do	Stems, leaves, fruits, washed	10:10	.20	1.61	.10–0.45	Gough and Severson (1981b).
New Mexico: San Juan County, Four Corners Powerplant	Stems, leaves	3:3	.26	2.98	.08–0.7	Cannon and Swanson (1979).
North Dakota: Mercer County, Beulah North Mine	Terminal 10–15 cm (stems, leaves)	3:3	.18	2.66	.06–0.35	Ebens and Shacklette (1982).
Oliver County	Leaves and stems	6:6	.35	2.45	.08–1.0	J.A. Erdman (unpub. data, 1978).
Oliver County, Beulah South Mine	Stems, leaves, fruits, washed	10:10	.12	1.37	.08–0.20	Gough and Severson (1981b).
Stark County, Husky Mine	do	10:10	.17	1.70	.10–0.45	Do.
Ward County, Velva Mine	Terminal 10–15 cm (stems, leaves)	3:3	.33	1.18	.30–0.40	Ebens and Shacklette (1982).
Do	Stems, leaves, fruits, washed	10:10	.37	1.37	.25–0.55	Gough and Severson (1981b).
Wyoming: Converse County, D. Johnston Mine	Terminal 10–15 cm (stems, leaves)	3:3	.34	2.11	.20–0.80	Ebens and Shacklette (1982).
<u>Collected in association with the Uncompahgre Reclamation Project:</u>						
Colorado: Delta and Montrose Counties		118:129	.33	--	<.03–9.5	Crock and others (1994).
Alluvium derived from Tertiary terraces and fans	Leaves and stems	25:26	.25	2.73	<.03–1.8	Do.
Quaternary alluvium derived from Dakota Sandstone	do	1:1	--	--	.31	Do.
Quaternary alluvium derived from Mancos Shale	do	31:34	.56	4.06	<.03–8.4	Do.
Quaternary alluvium (flood plains of streams)	do	21:22	.48	3.27	<.03–9.5	Do.
Soil derived from Dakota Sandstone	do	10:11	.12	2.73	<.03–0.69	Do.
Soil derived from Mancos Shale	do	31:35	.28	3.25	<.03–1.6	Do.
Barley (*Hordeum vulgare*):						
Northern Great Plains (North Dakota, Montana; Saskatchewan, Canada)	Grain, cleaned	18:18	.45	1.88	.20–1.8	Ebens and Shacklette (1982).
South Dakota: Harding County, cultivar trial plot	do	7:7	.097	1.09	.08–0.10	Erdman and Moul (1982).
Oats (*Avena sativa*):						
Northern Great Plains (North Dakota, South Dakota, Montana; Saskatchewan, Canada)	do	21:21	.48	1.60	.15–1.0	Ebens and Shacklette (1982).
South Dakota: Harding County, cultivar trial plot	do	23:23	.15	1.19	.10–0.20	Erdman and Moul (1982).
Durum wheat (*Triticum durum*):						
Northern Great Plains (North Dakota, Montana; Saskatchewan, Canada)	do	20:20	.84	1.60	.40–2.2	Ebens and Shacklette (1982).
South Dakota: Harding County, cultivar trial plot	do	7:7	.16	1.15	.15–0.20	Erdman and Moul (1982).

Table 3. Se contents of agricultural crops—Continued.

Species sampled	Plant part sampled	Detection ratio	GM	GD	Observed range	Reference
Wheat (*Triticum aestivum*):						
Hard red winter wheat:						
Northern Great Plains (North Dakota, South Dakota, Montana; Saskatchewan, Canada)	Grain, cleaned	17:17	0.44	1.63	0.15–1.0	Erdman and Gough (1978).
Montana: Rosebud County, Big Sky Mine	do	3:3	.41	1.56	.25–0.60	Do.
South Dakota: Harding County, cultivar trial plot	do	19:19	.17	1.30	.10–0.40	Erdman and Moul (1982).
Hard red spring wheat:						
Northern Great Plains (North Dakota, South Dakota, Montana; Saskatchewan, Canada)	do	54:54	.64	1.85	.15–2.2	Ebens and Shacklette (1982).
North Dakota: Oliver County	do	6:6	.24	1.17	.20–0.30	J.A. Erdman (unpub. data, 1978).
South Dakota: Harding County, cultivar trial plot	do	19:19	.17	1.16	.15–0.20	Erdman and Moul (1982).
California: San Joaquin Valley	do	32:32	.18	2.15	.03–0.56	Severson and others (1991).
Do	Straw, head removed	8:8	.15	1.86	.05–0.20	Do.
Wheat, hard red winter (*Triticum asetivum*):						
Colorado: Adams County, soil amended with sewage sludge:						
Control samples	Grain, cleaned	6:6	.29	1.20	.25–0.40	Erdman and Tourtelot (1976).
Filter-cake application, 20 to 45 tons/acre	do	6:6	.40	1.23	.30–0.50	Do.
Sludge application, 20 tons/acre	do	6:6	.31	1.33	.20–0.45	Do.
Sludge application, 40 tons/acre	do	6:6	.26	1.21	.20–0.35	Do.
Sludge application, 55 tons/acre	do	6:6	.42	1.24	.35–0.60	Do.
Sludge application, 90 tons/acre	do	1:1	--	--	.30	Do.
Wheat, soft white club (*Triticum compactum*):						
Washington: Adams and Walla Walla Counties	do	20:20	.029	1.80	.01–0.08	Gough and others (1981).
Do	Immature grain head, washed	18:18	.025	1.66	.01–0.06	Do.
Do	Stems, leaves (green), washed	17:18	.017	1.58	<.01–0.04	Do.
Rye (*Secale cereale*):						
Canada: southern Saskatchewan	Grain, cleaned	1:1	--	--	.80	J.A. Erdman, unpub. data (1977).
Soybeans (*Glycine max*):						
Missouri, flood-plain forest	Seeds	10:10	.17	2.68	.06–1.25	Erdman and others (1976a).
Glaciated prairie	do	10:10	.098	1.83	.04–0.25	Do.
Oak-hickory forest	do	9:9	.077	1.94	.04–0.40	Do.
Unglaciated prairie	do	8:8	.097	2.28	.04–0.35	Do.
Corn (*Zea mays*):						
Field corn:						
Missouri, flood-plain forest	Grains, cut from cob	8:8	.062	2.41	.01–0.20	Do.
Glaciated prairie	do	10:10	.072	2.61	.02–0.40	Do.
Oak-hickory forest	do	10:10	.040	2.96	.02–0.50	Do.
Unglaciated prairie	do	10:10	.047	1.88	.02–0.15	Do.
Sweet corn:						
Florida: Palm Beach County	do	8:10	.0048	1.40	<.005–0.01	Shacklette (1980).

Idaho: Twin Falls County	do	10:10	.010	1.59	.005–0.02	Do.
Michigan: Berrien County	do	10:10	.014	1.44	.01–0.02	Do.
New Jersey: Salem County	do	10:10	.026	1.79	.01–0.04	Do.
U.S.A., purchased in retail markets	do	8:11	.025	2.38	<.01–0.10	Shacklette and others (1978).
Cabbage (*Brassica oleracea*):						
Arizona: Yuma County	Head, washed and sliced	10:10	.31	1.45	.15–0.45	Shacklette (1980).
Michigan: Berrien County	do	2:2	.11	4.16	.04–0.30	Do.
New Jersey: Cumberland County	do	2:2	.057	1.63	.04–0.08	Do.
Texas: Hidalgo County	do	10:10	.10	1.36	.08–0.20	Do.
U.S.A., purchased in retail markets	do	11:11	.078	2.91	.02–0.50	Shacklette and others (1978).
Chinese cabbage (*Brassica pekinensis*):						
Florida: Palm Beach County	do	2:2	.0071	1.63	.005–0.01	Shacklette (1980).
Carrots (*Daucus carota*):						
California: Imperial County	Roots, washed and peeled	10:10	.13	1.50	.08–0.25	Do.
Texas: Hidalgo County	do	10:10	.032	1.40	.02–0.04	Do.
U.S.A., purchased in retail markets	do	11:11	.08	2.38	.01–0.20	Shacklette and others (1978).
Cucumber (*Cucumis sativus*):						
California: San Joaquin County	Fruit, washed and sliced	10:10	.098	1.50	.06–0.20	Shacklette (1980).
Michigan: Berrien County	do	10:10	.034	1.66	.02–0.05	Do.
New York: Wayne County	do	2:2	.069	1.23	.06–0.08	Do.
U.S.A., purchased in retail markets	do	11:11	.088	2.23	.04–0.40	Shacklette and others (1978).
Dry beans (*Phaseolus vulgaris*):						
California: San Joaquin County	Seeds, cleaned	10:10	.020	--	.02–0.02	Shacklette (1980).
Colorado: Mesa County	do	10:10	.11	1.65	.04–0.20	Do.
Idaho: Twin Falls County	do	10:10	.016	1.40	.01–0.02	Do.
New York: Wayne County	do	10:10	.022	1.42	.02–0.06	Do.
U.S.A., purchased in retail markets	do	11:11	.068	3.07	.02–0.35	Shacklette and others (1978).
Green beans (*Phaseolus vulgaris*):						
Florida: Palm Beach County	Pods, washed and sliced	10:10	.021	1.25	.02–0.04	Shacklette (1980).
Idaho: Twin Falls County	do	10:10	.027	1.53	.02–0.06	Do.
Michigan: Berrien County	do	2:2	.040	1.00	.04–0.04	Do.
New Jersey: Cumberland County	do	10:10	.045	1.27	.04–0.08	Do.
New York: Wayne County	do	10:10	.020	1.25	.02–0.04	Do.
U.S.A., purchased in retail markets	do	11:11	.075	2.66	.02–0.30	Shacklette and others (1978).
Lettuce (*Lactuca sativa*):						
California: Imperial County	Head, washed and sliced	10:10	.18	1.26	.10–0.20	Shacklette (1980).
Florida: Palm Beach County	do	8:9	.008	1.77	<.01–0.02	Do.
New Jersey: Cumberland County	do	10:10	.078	1.54	.04–0.20	Do.
Texas: Hidalgo County	do	10:10	.077	1.36	.04–0.10	Do.
U.S.A., purchased in retail markets	do	11:11	.057	1.53	.04–0.15	Shacklette and others (1978).
Potatoes (*Solanum tuberosum*):						
Idaho: Twin Falls County	Tubers, washed and peeled	10:10	.010	1.48	.005–0.02	Shacklette (1980).
New Jersey: Cumberland County	do	10:10	.021	1.25	.02–0.04	Do.
New York: Wayne County	do	10:10	.009	1.48	.005–0.02	Do.
Washington: Yakima County	do	10:10	.008	1.62	.005–0.02	Do.

Table 3. Se contents of agricultural crops—Continued.

Species sampled	Plant part sampled	Detection ratio	GM	GD	Observed range	Reference
Potatoes (*Solanum tuberosum*)—Continued						
Washington: Yakima County	Tubers, washed and peeled	5:12	0.003	--	<0.003–0.005	Gough and others (1986).
U.S.A., purchased in retail markets	do	11:11	.065	2.44	.02–0.30	Shacklette and others (1978).
Eggplant (*Solanum melongena*):						
Michigan: Berrien County	Fruit, peeled and sliced	2:2	.014	1.63	.01–0.02	Shacklette (1980).
Tomatoes (*Lycopersicum esculentum*):						
California: San Joaquin County	Fruit, washed and sliced	10:10	.16	1.78	.08–0.35	Do.
Florida: Palm Beach County	do	9:9	.015	2.71	.01–0.02	Do.
Michigan: Berrien County	do	10:10	.027	1.53	.01–0.06	Do.
New Jersey: Cumberland County	do	10:10	.027	1.53	.02–0.05	Do.
Washington: Yakima County	do	10:10	.035	2.44	.01–0.15	Do.
Do	do	12:12	.011	2.06	.003–0.04	Gough and others (1986).
U.S.A., purchased in retail markets	do	11:11	.054	2.22	.02–0.35	Shacklette and others (1978).
Asparagus (*Asparagus officinalis*):						
California: San Joaquin County	Stalks, washed and sliced	10:10	.57	1.12	.45–0.65	Shacklette (1980).
Colorado: Adams County	do	1:1	--	--	2.5	H.A. Tourtelot (unpub. data, 1978).
Endive (*Cichorium endivia*):						
Florida: Palm Beach County	Leaves, washed	2:2	.06	1.91	.04–0.10	Shacklette (1980).
Onions (*Allium cepa*):						
Texas: Hidalgo County	Bulb, sliced	10:10	.042	1.38	.02–0.06	Do.
U.S.A., purchased in retail markets	do	11:11	.080	2.64	.02–0.35	Shacklette and others (1978).
Parsley (*Petroselinum crispum*):						
Florida: Palm Beach County	Leaves, washed	2:2	.028	1.63	.02–0.04	Shacklette (1980).
Peppers (*Capsicum frutescens*):						
Michigan: Berrien County	Fruit, seeds removed	2:2	.02	--	.02–0.02	Do.
Pears (*Pyrus communis*):						
California: San Joaquin County	Fruit, peeled, core removed	5:10	.0035	1.78	<.005–0.01	Do.
Colorado: Mesa County	do	10:10	.012	1.60	.005–0.02	Do.
Michigan: Berrien County	do	6:10	.0047	2.12	<.005–0.01	Do.
New York: Wayne County	do	7:10	.0048	2.04	<.005–0.02	Do.
Washington: Yakima County	do	7:10	.0035	1.78	<.005–0.02	Do.
Do	do	1:12	--	--	<.003–0.003	Gough and others (1986).
Apples (*Pyrus malus*):						
Colorado: Mesa County	do	10:10	.014	1.63	.01–0.04	Shacklette (1980).
Michigan: Berrien County	do	0:10	--	--	<.005	Do.
New Jersey: Gloucester County	do	6:10	.0040	1.32	<.005–0.005	Do.

New York: Wayne County	do	2:10	--	--	<.005–0.01	Do.
Washington: Yakima County	do	2:10	--	--	<.005–0.005	Do.
Do	do	6:12	.003	--	<.003–0.005	Gough and others (1986).
U.S.A., purchased in retail markets	do	1:11	--	--	<.01–0.02	Shacklette and others (1978).
Cantaloupe (*Cucumis melo*):						
Michigan: Berrien County	Fruit, peeled, seeds removed	2:2	.028	1.63	.02–0.04	Shacklette (1980).
Grapes, American (*Vitis labruscana*):						
Michigan: Berrien County	Fruit plus seeds, stems removed	10:10	.011	1.48	.005–0.02	Shacklette (1980).
New York: Wayne County	do	10:10	.0076	1.43	.005–0.01	Do.
Washington: Yakima County	do	10:10	.018	5.20	.005–0.15	Do.
Do	do	10:12	.0048	1.97	<.003–0.005	Gough and others (1986).
Grapes, European (*Vitis vinifera*):						
California: San Joaquin County	Fruit, washed, seeds removed	0:10	--	--	<.005	Shacklette (1980).
Washington: Yakima County	do	7:10	.0051	2.14	<.005–0.02	Do.
Do	do	8:12	.004	--	<.003–0.015	Gough and others (1986).
Grapefruit (*Citrus paradisi*):						
Arizona: Yuma County	Fruit, peeled, seeds removed	10:10	.011	1.34	.01–0.02	Shacklette (1980).
California: Riverside County	do	9:10	.022	2.30	<.005–0.06	Do.
Florida: Palm Beach County	do	4:9	.003	2.32	<.005–0.01	Do.
Texas: Hidalgo County	do	9:10	.011	1.99	<.005–0.02	Do.
Oranges (*Citrus sinensis*):						
Arizona: Yuma County	do	10:10	.0075	1.43	.005–0.01	Do.
California: Riverside County	do	10:10	.020	1.39	.01–0.04	Do.
Florida: Palm Beach County	do	1:9	--	--	<.005–0.005	Do.
Texas: Hidalgo County	do	8:9	.0089	1.42	<.005–0.01	Do.
U.S.A., purchased in retail markets	do	10:11	.020	1.91	<.01–0.06	Shacklette and others (1978).
Peaches (*Prunus persica*):						
California: San Joaquin County	Fruit, peeled, pit removed	2:10	--	--	<.005–0.005	Shacklette (1980).
Colorado: Mesa County	do	10:10	.012	1.40	.01–0.02	Do.
New York: Wayne County	do	5:10	.0036	1.90	<.005–0.02	Do.
Washington: Yakima County	do	6:10	.0044	1.99	<.005–0.01	Do.
Do	do	0:12	--	--	<.003	Gough and others (1986).
Plums (*Prunus domestica*):						
Colorado: Mesa County	Fruit, pit removed	10:10	.011	1.55	.005–0.02	Shacklette (1980).
Michigan: Berrien County	do	8:10	.0051	1.54	<.005–0.01	Do.
New York: Wayne County	do	6:10	.0042	1.83	<.005–0.01	Do.
Washington: Yakima County	do	5:10	.0036	2.90	<.005–0.02	Do.
Do	do	6:12	--	--	<.003–0.005	Gough and others (1986).

Table 4. Se contents of native plant species.

[All values in parts per million dry weight. Detection ratio is a fraction in which the numerator is the number of samples with uncensored values and the denominator is the total number of samples. GD, geometric deviation; GM, geometric mean. Do., ditto]

Species sampled	Plant part sampled	Detection ratio	GM	GD	Observed range	Reference
Soil moss (*Tortula ruralis*):						
Oregon: Malheur County	Whole plant	11:11	0.11	1.58	0.06–0.30	J.A. Erdman (unpub. data, 1980).
Spanish moss (*Tillandsia usneoides*):						
Georgia: Chatham County	do	80:80	.26	1.29	.15–0.40	H.A. Tourtelot (unpub. data, 1981).
Lichen (*Usnea hirta*):						
Colorado: Larimer County	do	1:1	--	--	.90	H.T. Shacklette (unpub. data, 1979).
Montana: Powder River and Meagher Counties	do	6:6	.69	1.30	.60–0.90	Do.
New Mexico: Rio Arriba County	do	1:1	--	--	.50	H.T. Shacklette (unpub. data, 1976).
Wyoming: Campbell County	do	2:2	.90	--	.90–0.90	Do.
Lincoln County	do	4:4	.82	1.15	.70–1.0	H.T. Shacklette (unpub. data, 1979).
Lichen (*Usnea cavernosa*):						
Colorado: Baca and Larimer Counties	do	7:7	.64	1.18	.50–0.75	Do.
Lichen (*Usnea trichodea*):						
Georgia: Emanuel County	do	1:1	--	--	.25	H.T. Shacklette (unpub. data, 1976).
Mississippi: Copiah County	do	1:1	--	--	.25	Do.
Texas: Bastrop County	do	1:1	--	--	.90	Do.
Lichen (*Usnea* sp.):						
Florida: Walton County	do	1:1	--	--	.90	Do.
North Carolina: Orange County	do	1:1	--	--	.70	Do.
Washington: King County	do	1:1	--	--	.50	Do.
Lichen (*Alectoria fremontii*):						
Washington: Okanogan County	do	1:1	--	--	.20	Do.
Lichen (*Alectoria sarmentosa*):						
Washington: Lewis, Pierce, and Okanogan Counties	do	3:3	.068	1.61	.04–0.10	Do.
Lichen (*Alectoria* sp.)						
Idaho: Idaho County	do	1:1	--	--	.20	Do.
Montana: Mineral and Missoula Counties	do	2:2	.19	1.44	.15–0.25	Do.
Washington: Okanogan County	do	1:1	--	--	.15	Do.
Lichen (*Ramalina farinacea*):						
England: Devonshire	do	2:2	.85	--	.85	Do.
Lichen (*Ramalina fastigiata*):						
England: Devonshire	do	2:2	.87	1.23	.75–1.0	Do.

Lichen (*Ramalina menziesii*):						
California: Sonoma County	do	1:1	--	--	.15	Do.
Lichen (*Ramalina* sp.):						
Texas: Kenedy County	do	1:1	--	--	.65	Do.
Lichen (*Evernia mesomorpha*):						
Michigan: Marquette County	do	3:3	1.07	2.10	.65–2.5	Do.
Lichen (*Pseudevernia intensa*):						
Texas: Brewster County	do	1:1	--	--	.60	Do.
Lichen (*Letharia vulpina*):						
Montana: Mineral County	do	1:1	--	--	.10	Do.
Washington: Okanogan County	do	1:1	--	--	.15	Do.
Soil lichen (*Parmelia chlorochroa*):						
Colorado: Montrose County	Whole plant, washed	1:1	--	--	.30	L.P. Gough (unpub. data, 1978).
Idaho: Custer County	do	5:5	.14	1.20	.10–0.15	J.A. Erdman (unpub. data, 1981).
Montana: Rosebud and Powder River Counties	do	30:30	.27	1.11	.25–0.35	Gough and Erdman (1978).
Do	do	35:35	.26	1.24	.20–0.40	L.P. Gough (unpub. data, 1979).
Wyoming and Montana: Powder River Basin	do	22:22	.35	1.42	.20–0.70	Erdman and Gough (1977).
Wyoming: Campbell and Crook Counties	do	93:93	.34	1.31	.15–1.0	R.R. Tidball (unpub. data, 1981).
Converse County, D. Johnston Mine	do	18:18	.76	1.62	.35–1.4	Gough and Erdman (1977).
Soil lichen (*Cladonia skottsbergii*):						
Hawaii: Hawaii Volcanoes National Park	Above ground, washed	6:6	1.10	1.66	.70–2.0	Connor (1979).
Joint-fir (*Ephedra torreyana*):						
New Mexico: San Juan County	Terminal branch tips	2:2	.17	2.17	.10–0.30	Cannon and Swanson (1979).
Sedge (*Carex gymnoclada*):						
Idaho: Valley and Lemhi Counties	Above ground	9:11	.016	2.12	<.01–0.10	J.A. Erdman (unpub. data, 1980).
Bullrush (*Scirpus* sp.):						
California: Merced County	Seeds	1:1	--	--	.45	T.F. Harms (unpub. data, 1984).
Do	Tuber	1:1	--	--	2.4	Do.
Bluebunch wheatgrass (*Agropyron spicatum*):						
Idaho: Soda Springs	Above ground, unwashed splits	12:12	1.6	1.20	1.2–2.0	Severson and Gough (1979).
Do	Above ground, washed splits	12:12	1.3	1.26	.80–1.6	Do.
Soda Springs, near phosphate-processing plant	Above ground, washed	31:31	.20	2.17	.06–1.2	Do.
Crested wheatgrass (*Agropyron cristatum* or *A. desertorum*):						
North Dakota: Adams, Morton, and Stark Counties	Above ground	6:6	.14	1.91	.06–0.30	J.A. Erdman (unpub. data, 1978).
Oliver County, on coal spoil	do	6:6	.19	1.29	.15–0.25	Do.
Wyoming: Carbon County, Seminoe No. 2 Coal Mine	Above ground, washed	10:10	.054	1.45	.04–0.10	Gough and Severson (1981b).
Converse County, D. Johnston Coal Mine	do	10:10	.21	1.78	.10–0.45	Do.
Do	Above ground, on mine spoil	20:20	.27	1.73	.10–0.70	Erdman and Ebens (1979).
Do	Above ground, on nearby soil	20:20	.23	1.91	.10–0.60	Do.
Intermediate wheatgrass (*Agropyron intermedium*):						
Colorado: Routt County, Energy Fuels Mine	Above ground, washed	10:10	.17	1.45	.10–0.25	Gough and Severson (1981b).
Routt County, Seneca No. 2 Mine	do	10:10	.19	1.77	.06–0.45	Do.

Table 4. Se contents of native plant species—Continued.

Species sampled	Plant part sampled	Detection ratio	GM	GD	Observed range	Reference
Intermediate wheatgrass (*Agropyron intermedium*)—Continued						
North Dakota: Adams, Morton, and Stark Counties	Above ground	6:6	0.13	1.53	0.10–0.30	J.A. Erdman (unpub. data, 1978).
Oliver County, on coal spoil	do	6:6	.23	1.80	.10–0.55	Do.
Oliver County, South Beulah Mine	Above ground, washed	10:10	.054	1.31	.06–0.15	Gough and Severson (1981b).
Stark County, Husky Mine	do	10:10	.088	1.51	.04–0.15	Do.
Ward County, Velva Mine	do	10:10	.098	1.50	.06–0.20	Do.
Slender wheatgrass (*Agropyron trachycaulum*):						
Montana: Big Horn County, Decker Mine	do	10:10	.057	1.41	.04–0.10	Do.
Big Horn County, Absaloka Mine	do	10:10	.025	1.40	.02–0.04	Do.
Rosebud County, Big Sky Mine	do	10:10	.13	1.71	.04–0.25	Do.
Western wheatgrass (*Agropyron smithii*):						
New Mexico: San Juan County	do	30:30	.081	1.52	.04–0.25	T.F. Harms (unpub. data, 1979).
Wheatgrass (*Agropyron* sp.):						
Washington: Stevens County, near uranium mills	Whole plant	6:6	.011	1.37	.01–0.02	T.K. Hinkley (unpub. data, 1980).
Big bluestem grass (*Andropogon gerardi*):						
Missouri	Above ground	5:5	.030	1.86	.02–0.08	H.T. Shacklette (unpub. data, 1972).
Grama grass (*Bouteloua gracilis*):						
New Mexico: Valencia County, near uranium mills	Whole uprooted plant	25:25	.70	5.84	.02–9.0	T.K. Hinkley (unpub. data, 1980).
Montana and Wyoming: Powder River Basin	Whole plant, washed	46:46	.20	1.81	.08–1.4	Erdman and Gough (1975).
Smooth brome grass (*Bromus inermis*):						
Wyoming: Converse County, D. Johnston Mine	Above ground, washed	10:10	.14	1.82	.06–0.50	Gough and Severson (1981b).
North Dakota: Adams, Morton, and Stark Counties	Above ground	6:6	.22	1.92	.10–0.55	J.A. Erdman (unpub. data, 1978).
Oliver County, on coal spoil	do	6:6	.23	1.50	.15–0.40	Do.
Cheatgrass (*Bromus tectorum*):						
Idaho: Pocatello, near phosphate-processing plant	Above ground, washed	27:27	.088	2.08	.02–0.45	Severson and Gough (1976).
Bluejoint (*Calamagrostis canadensis*):						
Alaska: Tyonek B–5 quadrangle, Capps Coal Field	Above ground	24:26	.073	1.68	<.05–0.20	Gough and Severson (1983).
Rough Fescue (*Festuca scabrella*):						
Washington: Stevens County, near uranium mill	Whole plant	3:8	<.01	--	<.01–0.01	T.K. Hinkley (unpub. data, 1980).
Fescue (*Festuca altaica*):						
Alaska: Tyonek B–5 quadrangle, Capps Coal Field	Above ground	63:64	.14	1.53	<.05–0.40	Gough and Severson (1983).
Galleta grass (*Hilaria jamesii*):						
New Mexico: San Juan Basin	Whole uprooted plant, washed	25:25	.12	1.62	.06–0.45	Gough and Severson (1981a).
Indian rice grass (*Oryzopsis hymenoides*):						
New Mexico: San Juan County	Above ground	14:14	.28	1.72	.08–0.55	Connor and others (1976a).

Bluegrass (*Poa* sp.):						
Washington: Stevens County, near uranium mill	Whole plant	1:1	--	--	.01	T.K. Hinkley (unpub. data, 1980).
Alkali sacaton grass (*Sporobolus airoides*):						
New Mexico: rehabilitation site, San Juan Coal Mine	Above ground, washed	6:6	.096	1.13	.08–0.10	Gough and Severson (1981a).
Swamp timothy (*Phleum* sp.):						
California: Merced County	Seeds	1:1	--	--	1.0	T.F. Harms (unpub. data, 1984).
Cattail (*Typha* sp.):						
California: Merced County	Tuber	1:1	--	--	2.2	Do.
Water parsnip (*Berula erecta*):						
New Mexico: San Juan County	Leaves and stems	2:2	.063	1.39	.05–0.075	Cannon and Swanson (1979).
Snowberry (*Symphoricarpos oreophilus*):						
Idaho: Valley County	Above ground	0:2	--	--	<.01	J.A. Erdman (unpub. data, 1980).
Buckbush (*Symphoricarpos orbiculatus*):						
Missouri, cedar glade	Stems	49:49	.023	1.33	.02–0.04	Erdman and others (1976b).
Glaciated prairie	do	47:47	.043	1.45	.02–0.08	Do.
Oak-hickory forest	do	39:39	.031	1.47	.02–0.06	Do.
Oak-hickory-pine forest	do	50:50	.021	1.36	.02–0.04	Do.
Unglaciated prairie	do	46:46	.038	1.49	.02–0.08	Do.
Flood-plain forest	do	4:4	.047	1.97	.02–0.10	J.A. Erdman (unpub. data, 1972).
Four-wing saltbush (*Atriplex canescens*):						
Colorado: Mesa County	Leaves and stems	1:1	--	--	2.2	B.M. Erickson (unpub. data, 1981).
Rio Blanco County	do	5:5	.10	1.26	.08–0.15	Anderson (1982).
Montana: Big Horn County, Decker Coal Mine	Leaves and woody stems	10:10	.32	1.75	.15–0.90	Gough and Severson (1981b).
New Mexico: San Juan Basin	Leaves and stems	10:10	.81	3.07	.15–4.5	Gough and Severson (1981a).
San Juan County, San Juan Mine	do	6:6	.22	2.10	.10–0.45	Do.
Valencia County, near uranium mill	do	11:11	2.79	3.32	.5–30	T.K. Hinkley (unpub. data, 1980).
Wyoming: Sweetwater County, Jim Bridger Mine	Leaves and woody stems	10:10	.70	1.63	.25–1.2	Gough and Severson (1981b).
Shadscale (*Atriplex confertifolia*):						
Arizona: Apache County	Leaves and stems	10:10	.44	2.41	.15–3.0	B.M. Erickson (unpub. data, 1981).
Coconino County	do	10:10	.28	1.53	.15–0.50	Do.
Colorado: Delta County	do	10:10	2.30	6.72	.10–28	Do.
Mesa County	do	10:10	.65	3.50	.10–6.0	Do.
New Mexico: San Juan County	do	10:10	.23	2.31	.075–0.70	Cannon and Swanson (1979).
Do	do	20:20	.26	3.00	.04–2.6	B.M. Erickson (unpub. data, 1981).
Utah: Emery County	do	9:9	1.52	2.93	.25–9.5	Do.
Grand County	do	10:10	1.03	2.58	.30–4.5	Do.
Sanpete County	do	20:20	.63	2.03	.20–4.5	B.M. Erickson (unpub. data, 1983).
Sanpete County, summer collection	Leaves	21:21	1.63	1.75	.50–6.0	Do.
Sanpete County, winter collection	Stems	20:20	.38	1.51	.20–0.85	Do.
Sanpete and Uintah Counties	Above ground	10:10	.13	1.90	.06–0.35	B.M. Erickson (unpub. data, 1982).
Wyoming: Sweetwater County	Leaves and stems	20:20	.39	4.37	.04–18	B.M. Erickson (unpub. data, 1981).
Mat saltbush (*Atriplex corrugata*):						
New Mexico: San Juan County	Leaves and stems	3:3	.79	5.25	.20–5.0	Cannon and Swanson (1979).

Table 4. Se contents of native plant species—Continued.

Species sampled	Plant part sampled	Detection ratio	GM	GD	Observed range	Reference
Quailbush (*Atriplex lentiformis*):						
California: San Joaquin Valley	Leaves	17:17	0.43	3.73	0.08–7.5	Izbicki and Harms (1986).
Nuttall's saltbush (*Atriplex nuttalli*):						
New Mexico: San Juan County	Leaves and stems	2:2	.67	3.12	.30–1.5	Cannon and Swanson (1979).
Powell's saltbush (*Atriplex powelli*):						
New Mexico: San Juan County	do	3:3	.87	5.08	.20–5.0	Do.
Spiny hopsage (*Atriplex spinosa*):						
Idaho: Lemhi County	Above ground	2:2	.10	--	.10–0.10	J.A. Erdman (unpub. data, 1980).
Winterfat (*Ceratoides lanata*):						
New Mexico: Valencia County, near uranium mill	Leaves and stems	1:1	--	--	.30	T.K. Hinkley (unpub. data, 1980).
Greasewood (*Sarcobatus vermiculatus*):						
Idaho: Custer County	Above ground	1:1	--	--	1.0	J.A. Erdman (unpub. data, 1981).
Sand sagebrush (*Artemisia filifolia*):						
New Mexico: Valencia County, near uranium mill	Leaves and stems	2:2	.26	3.96	.10–0.70	T.K. Hinkley (unpub. data, 1980).
Silver sagebrush (*Artemisia cana*):						
Montana and Wyoming: Powder River Basin, paired samples with big sagebrush	do	11:11	.52	2.17	.15–2.2	J.A. Erdman (unpub. data, 1975).
Wyoming: Converse, Platte, and Natrona Counties	do	77:77	.49	2.05	.10–2.0	Anderson and Keith (1977).
Big sagebrush (*Artemisia tridentata*):						
Idaho: Butte County	Current year's growth	25:26	.068	3.21	<.01–1.0	J.A. Erdman (unpub. data, 1988).
Custer County	Leaves and stems	13:13	.038	1.90	.02–0.15	J.A. Erdman (unpub. data, 1981).
Pocatello, subsp. *tridentata*	do	25:25	.10	1.78	.04–0.60	Severson and Gough (1976).
Soda Springs	do	27:27	.14	2.15	.06–1.2	Severson and Gough (1979).
Valley County, subsp. *vaseyana*	do	6:6	.024	2.15	.02–0.06	J.A. Erdman (unpub. data, 1980).
Montana and Wyoming: Powder River Basin	do	41:41	.43	2.63	.08–4.8	Connor and others (1976b).
Do	do	64:64	.31	2.25	.10–2.0	Tidball and others (1974).
Montona and Wyoming: Powder River Basin, paired samples with silver sage	do	11:11	.27	2.44	.10–1.0	J.A. Erdman (unpub. data, 1975).
Nevada: Elko County	Wood	14:20	.011	1.53	<.01–0.02	J.A. Erdman (unpub. data, 1981).
Humboldt County	do	5:24	<.01	--	<.01–0.02	Do.
Do	Current year's growth	22:22	.10	2.70	.01–0.60	Erdman and others (1988).
New Mexico: San Juan County	Leaves and stems	3:3	.086	1.14	.080–0.10	Cannon and Swanson (1979).
Oregon: Malheur County	Wood	31:36	.011	1.44	<.01–.02	J.A. Erdman (unpub. data, 1980).
Utah: Carbon County, subsp. *tridentata*	Leaves	9:9	.36	1.18	.25–0.40	Do.
Carbon County, subsp. *vaseyana*	do	9:9	.27	1.37	.15–0.45	Do.
Carbon County, subsp. *wyomingensis*	do	9:9	.35	1.30	.20–0.45	Do.
Washington: Adams, Franklin, and Lincoln Counties	Leaves and stems (washed)	12:12	.031	2.59	.01–0.10	L.P. Gough (unpub. data, 1982).
Do	Leaves and stems (unwashed)	12:12	.035	2.48	.01–0.10	Do.

Wyoming: Converse County, D. Johnston Mine	Leaves and stems	12:12	.36	2.08	.15–1.6	Connor and others (1976b).
Converse County, subsp. *wyomingensis*	Stems	11:11	.79	2.79	.20–10	J.A. Erdman (unpub. data, 1980).
Sublette County, subsp. *vaseyana*	Leaves and stems	12:12	.025	1.41	.02–0.04	L.P. Gough (unpub. data, 1975).
Sublette County, subsp. *wyomingensis*	do	12:12	.070	1.29	.04–0.10	Do.
Sweetwater County	do	41:41	.15	2.59	.04–5.0	Anderson and Keith (1976).
Do	do	24:24	.14	2.00	.04–0.50	B.M. Erickson (unpub. data, 1979).
Sweetwater County, soil derived from Lewis Shale	do	14:14	.17	3.19	.04–2.5	Do.
Big sagebrush (*Artemisia tridentata*):						
Regional study	Leaves and stems (current year)	190:190	.11	3.23	.01–7.0	Gough and Erdman (1983).
Basin and Range Province	do	30:30	.11	4.65	.02–7.0	Do.
Colorado Plateaus Province	do	30:30	.17	3.05	.04–4.0	Do.
Columbia Plateaus Province	do	30:30	.063	2.76	.01–0.3	Do.
Middle Rocky Mountains	do	20:20	.093	4.49	.02–1.8	Do.
Northern Great Plains	do	20:20	.29	4.36	.04–2.0	Do.
Northern Rocky Mountains	do	20:20	.035	2.54	.01–0.15	Do.
Southern Rocky Mountains	do	20:20	.078	3.15	.02–0.90	Do.
Wyoming Basin Province	do	20:20	.18	4.13	.04–1.6	Do.
Big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*):						
Wyoming: Platte County, seasonal study:						
September 1975 collection	Young stems, leaves, and inflorescences	10:10	2.48	1.26	1.8–3.6	Gough and Erdman (1980).
Do	Older woody stems and leaves	10:10	1.02	1.39	.60–1.8	Do.
January 1976 collection	Young stems, leaves, and inflorescences	10:10	1.70	1.24	1.2–2.4	Do.
Do	Older woody stems and leaves	10:10	1.38	1.32	.95–2.4	Do.
April 1976 collection	Young stems, leaves and inflorescences	10:10	1.51	1.31	1.0–2.4	Do.
Do	Older woody stems and leaves	10:10	1.26	1.32	.85–2.2	Do.
July 1976 collection	Young stems, leaves, and inflorescences	10:10	1.26	1.48	.75–2.4	Do.
Do	Older woody stems and leaves	10:10	.86	1.28	.60–1.2	Do.
Big sagebrush (*Artemisia tridentata*)						
Wyoming, Natrona County, Kendrick Reclamation Project:						
Growing in Quaternary alluvium	Previous year's growth	16:16	.22	2.22	.06–1.2	See and others (1992).
Growing in Quaternary sand dunes	do	4:4	.25	1.65	.15–0.45	Do.
Soil derived from Cody Shale	do	14:14	.96	4.66	.10–9.5	Do.
Soil derived from Fort Union Formation	do	7:7	.52	2.53	.10–2.2	Do.
Soil derived from Fox Hills Sandstone	do	1:1	--	--	.30	Do.
Soil derived from Frontier Formation	do	11:11	.39	1.81	.20–1.6	Do.
Soil derived from Lance Formation	do	6:6	.79	2.33	.20–2.2	Do.
Soil derived from Meeteetse Formation	do	6:6	.53	1.20	.40–0.65	Do.
Soil derived from Mesa Verde Formation	do	8:8	.32	1.78	.15–0.80	Do.
Soil derived from Mowry and Thermopolis Shales	do	8:8	.36	2.14	.10–1.0	Do.
Soil derived from Steele Shale	do	2:2	.50	1.15	.45–0.55	Do.
Soil derived from White River Formation	do	8:8	.24	1.68	.10–0.55	Do.
Soil derived from Wind River Formation	do	10:10	.41	2.44	.10–2.0	Do.
Rabbitbrush (*Chrysothamnus nauseosus*):						
Idaho: Lemhi County	Leaves and stems	1:1	--	--	.08	J.A. Erdman (unpub. data, 1980).
New Mexico: San Juan County	do	2:2	.14	1.63	.10–0.20	Cannon and Swanson (1979).

Table 4. Se contents of native plant species—Continued.

Species sampled	Plant part sampled	Detection ratio	GM	GD	Observed range	Reference
Broom snakeweed (*Gutierrezia sarothrae*):						
New Mexico: San Juan Basin	Above ground	18:18	0.27	1.84	0.08–1.2	Gough and Severson (1981a).
San Juan County	do	27:27	.25	1.55	.10–0.45	Do.
Snakeweed (*Gutierrezia lucida*):						
New Mexico: San Juan County	do	2:2	.3	--	.3–0.3	Cannon and Swanson (1979).
Woody aster (*Xylorrhiza glabriuscula*):						
Wyoming: Natrona County	do	8:8	26	7.89	.40–240	J.A. Erdman (unpub. data, 1988).
Desert plume (*Stanleya pinnata*):						
Nevada: Mineral County	do	3:3	.90	14.2	.06–12	Cannon and others (1986).
Prince's plume (*Stanleya elata*):						
Nevada: Mineral County	do	2:2	.81	1.36	.65–1.0	Do.
Silverberry (*Elaeagnus commutata*):						
Alaska	Leaves and stems	1:1	--	--	.02	Gough and others (1991).
Crowberry (*Empetrum nigrum*):						
Alaska	do	3:3	.074	3.25	.02–0.20	Do.
Lapland cassiope (*Cassiope tetragona*):						
Alaska	do	1:1	--	--	.01	Do.
Cassiope (*Cassiope* sp.):						
Alaska	do	1:1	--	--	.04	Do.
Idaho: Valley County	Above ground	1:1	--	--	.02	J.A. Erdman (unpub. data, 1980).
Copperflower (*Cladothamnus pyrolaeflorus*):						
Alaska	Leaves and stems	1:1	--	--	.08	Gough and others (1991).
Labrador tea (*Ledum palustre*):						
Alaska	Leaves and stems	4:4	.022	1.23	.02–0.03	Do.
Grouseberry (*Vaccinium scoparium*):						
Idaho: Custer and Valley Counties	Above ground	5:5	.021	2.56	.01–0.10	J.A. Erdman (unpub. data, 1980).
Bilberry (*Vaccinium myrtillus*):						
Idaho: Valley County	do	2:2	.02	--	.02–0.02	Do.
Blueberry (*Vaccinium uliginosum*):						
Alaska	Leaves and stems	2:4	.011	1.99	<.01–0.03	Gough and others (1991).
Two-grooved poisonvetch (*Astragalus bisulcatus*):						
Wyoming: Converse County	Above ground	2:2	49	1.33	40–60	J.A. Erdman (unpub. data, 1980).
Natrona County	do	11:11	227	6.17	15–1,800	J.A. Erdman (unpub. data, 1988).

Woolly loco (*Astragalus mollissimus*):						
Texas: Brewster, Presidio, and Jeff Davis Counties	do	4:4	.12	1.59	.08–0.20	Erdman and others (1979).
Nuttall milkvetch (*Astragalus nuttallianus*):						
Texas: Brewster County	do	2:2	.069	1.23	.06–0.08	Do.
Diablo locoweed (*Astragalus oxyphysus*):						
California: western San Joaquin Valley	Leaves	14:14	.33	2.68	.08–3.5	Izbicki and Harms (1986).
Patterson poisonvetch (*Astragalus pattersonii*):						
Wyoming: Converse County	Above ground	2:2	18	1.94	11–28	B.M. Erickson (unpub. data, 1976).
Milkvetch (*Astragalus* sp.):						
Idaho: Custer County	do	1:1	--	--	.04	J.A. Erdman (unpub. data, 1980).
South Dakota: Harding County	do	1:1	--	--	1,200	J.A. Erdman (unpub. data, 1979).
Wyoming: Natrona County	do	4:4	9.5	33.70	.25–600	J.A. Erdman (unpub. data, 1988).
Two-leafed senna (*Cassia dumosa*):						
Texas: Presidio County	Leaves and stems	1:1	--	--	.65	Erdman and others (1979).
Cassia (*Cassia* sp.):						
Texas: Presidio County	do	1:1	--	--	.25	Do.
Japanese clover (*Lespedeza striata*):						
Missouri: Calloway County	Above ground	1:1	--	--	.20	Ebens and others (1973).
Lupine (*Lupinus* sp.):						
Idaho: Custer County	Flowers and fruits	1:1	--	--	.02	J.A. Erdman (unpub. data, 1980).
Do	Leaves and stems	4:4	.042	1.94	.02–0.10	Do.
Yellow sweetclover (*Melilotus officinalis*):						
Colorado: Jefferson County	do	2:2	.057	1.63	.04–0.08	J.A. Erdman (unpub. data, 1972).
Missouri: Calloway County	do	1:1	--	--	.40	Do.
Montana: Richland County, Savage Coal Mine	do	10:10	1.30	2.50	.60–6.0	Erdman and Ebens (1975).
Montana and North Dakota: paired samples with white sweetclover	do	12:12	.30	2.50	.04–1.2	Do.
North Dakota: Burke County, Kincaid Coal Mine	do	10:10	.17	2.28	.06–0.55	Do.
Mercer County, Beulah North Mine	do	10:10	.15	2.05	.08–0.60	Do.
Ward County, Velva Coal Mine	do	10:10	.49	2.07	.15–2.0	Do.
Wyoming: Converse County, D. Johnston Mine	do	10:10	.37	2.73	.10–3.0	Do.
Sheridan County, Hidden Valley Mine	do	10:10	.53	1.85	.15–1.2	Do.
White sweetclover (*Melilotus alba*):						
Colorado: Jefferson County	do	2:2	.049	1.33	.04–0.06	J.A. Erdman (unpub. data, 1972).
Missouri: Calloway County	Current year's growth	3:3	.22	1.54	.15–.35	Ebens and others (1973).
Do	Second year dead stems and seeds	3:3	.13	1.60	.08–0.20	Do.
Montana: Rosebud County, Big Sky Mine	Leaves and stems	10:10	.42	2.26	.08–1.0	Erdman and Ebens (1975).
Montona and North Dakota: paired samples with yellow sweetclover	do	12:12	.48	3.12	.04–1.8	Do.
Canada: Saskatchewan,Utility Mine	do	10:10	.23	1.93	.06–0.50	Do.
Catclaw mimosa (*Mimosa biuncifera*):						
Texas: Brewster and Presidio Counties	Fruits (pods)	25:25	.28	2.90	.04–3.0	Erdman and others (1979).
Do	Leaves	25:25	.15	2.72	.04–1.6	Do.

Table 4. Se contents of native plant species—Continued.

Species sampled	Plant part sampled	Detection ratio	GM	GD	Observed range	Reference
Sandfain (*Onobrychis viciaefolia*):						
Montana: Big Horn County, Absaloka Mine	Stems and fruits	10:10	0.029	1.53	0.02–0.06	Gough and Severson (1981b).
Beargrass (*Xerophyllum tenax*):						
Idaho: Valley County	Above ground	6:8	.014	2.06	<.01–0.04	J.A. Erdman (unpub. data, 1980).
Fireweed (*Epilobium alpinum*):						
Idaho: Valley County	do	0:1	--	--	<.01	Do.
Eriogonum (*Eriogonum leptophylum*):						
New Mexico: San Juan County	do	1:1	--	--	1.5	Cannon and Swanson (1979).
Eriogonum (*Eriogonum ovalifolium*):						
Idaho: Custer County	Caudex	1:1	--	--	.06	J.A. Erdman (unpub. data, 1980).
Ceanothus (*Ceanothus velutinus*):						
Idaho: Valley County	Leaves and stems	1:2	.012	2.12	<.01–0.02	Do.
Holodiscus (*Holodiscus dumosus*):						
Idaho: Valley County	do	1:1	--	--	.01	Do.
Cinquefoil (*Potentilla* sp.):						
Idaho: Valley County	Above ground	2:2	.01	--	.01–0.01	Do.
Bitterbrush (*Purshia tridentata*):						
Idaho: Lemhi County	do	3:3	.013	1.49	.01–0.02	Do.
Raspberry (*Rubus* sp.):						
Idaho: Valley County	do	1:2	.012	2.10	<.01–0.02	Do.
Creosote bush (*Larrea divaricata* subsp. *tridentata*):						
Texas: Presidio County	Leaves and stems	2:2	.50	1.63	.35–0.70	Erdman and others (1979).
Cedar (*Juniperus virginiana*):						
Missouri: Calloway County	Terminal branch tips	2:2	.10	--	.10–0.10	R.R. Tidball (unpub. data, 1971).
Cedar glade	do	50:50	.021	1.36	.01–0.04	Erdman and others (1976b).
Juniper (*Juniperus communis*):						
Idaho: Custer and Valley Counties	do	3:3	.018	2.81	.01–0.06	J.A. Erdman (unpub. data, 1980).
Juniper (*Juniperus* sp.):						
Texas: Brewster and Presidio Counties	do	8:8	.034	2.22	.01–0.08	Erdman and others (1979).
Subalpine fir (*Abies lasiocarpa*):						
Idaho: Valley County	Needles	3:9	<.01	--	<.01–0.02	J.A. Erdman (unpub. data, 1980).
Do	Stems	3:8	<.01	--	<.01–0.01	Do.
Do	Twigs	3:3	.01	--	.01–0.01	Do.

White spruce (*Picea glauca*):						
Alaska	Stems and leaves	46:76	.011	1.66	<.01–0.04	Gough and others (1991).
Black spruce (*Picea mariana*):						
Alaska	do	12:22	.0096	1.47	<.01–0.02	Do.
Sitka spruce (*Picea sitchensis*):						
Alaska	do	11:13	.017	1.85	<.01–0.04	Do.
Engelmann spruce (*Picea engelmanii*):						
Idaho: Valley County	Needles	0:3	<.01	--	<.01	J.A. Erdman (unpub. data, 1980).
Do	Stems	1:3	<.01	--	<.01–0.01	Do.
Do	Twigs	2:2	.01	--	.01–0.01	Do.
Lodgepole pine (*Pinus contorta*):						
Idaho: Valley, Lemhi, and Custer Counties	Needles	6:6	.041	2.81	.01–0.25	Do.
Do	Stems	3:4	.019	2.16	<.01–0.04	Do.
Shortleaf pine (*Pinus echinata*):						
Missouri: oak-hickory-pine forest	do	49:49	.062	1.71	.02–0.20	Erdman and others (1976b).
Limber pine (*Pinus flexilis*):						
Idaho: Custer County	Needles and stems	6:6	.078	1.96	.04–0.20	J.A. Erdman (unpub. data, 1980).
Valley County	Needles	5:6	.057	4.19	<.01–0.30	Do.
Do	Stems	5:6	.034	2.50	<.01–0.08	Do.
Ponderosa pine (*Pinus ponderosa*):						
Montana: Rosebud and Powder River Counties	Needles	28:28	.068	1.73	.02–0.20	J.A. Erdman (unpub. data, 1978).
Do	Stems	28:28	.075	1.26	.04–0.10	Do.
Do	Current year's needles	26:26	.050	1.70	.04–0.15	J.A. Erdman (unpub. data, 1979).
Do	Older needles	26:26	.12	1.77	.04–0.35	Do.
Washington: Stevens County, near uranium mills	Needles	15:16	.012	1.52	<.01–0.04	T.K. Hinkley (unpub. data, 1980).
Douglas-fir (*Pseudotsuga menziesii*):						
Alaska	Terminal branch tips	1:1	--	--	.03	Gough and others (1991).
Idaho: Lemhi and Custer Counties	do	6:6	.075	1.82	.04–0.15	J.A. Erdman (unpub. data, 1980).
Valley County	Needles	5:6	.024	2.26	<.01–0.08	Do.
Do	Stems	5:6	.012	1.60	<.01–0.02	Do.
Do	Twigs	3:3	.02	--	.02–0.02	Do.
Hemlock (*Tsuga heterophylla*):						
Alaska	Stems and leaves	11:11	.026	1.85	.01–0.06	Gough and others (1991).
Dwarf sumac (*Rhus copallina*):						
Missouri: flood-plain forest	Stems	15:15	.024	1.94	.01–0.10	H.T. Shacklette (unpub. data, 1972).
Oak-hickory forest	do	9:11	.011	1.53	<.01–0.02	Do.
Oak-hickory-pine forest	do	8:10	.014	1.86	<.01–0.04	Do.
Unglaciated prairie	do	6:6	.016	1.43	.01–0.02	Do.
Smooth sumac (*Rhus glabra*):						
Missouri: cedar glade	do	25:48	.0096	1.51	<.01–0.04	Erdman and others (1976b).
Flood-plain forest	do	47:48	.027	1.98	<.01–0.25	Do.
Glaciated prairie	do	49:50	.022	1.83	<.01–0.10	Do.

Table 4. Se contents of native plant species—Continued.

Species sampled	Plant part sampled	Detection ratio	GM	GD	Observed range	Reference
Smooth sumac (*Rhus glabra*)—Continued						
Missouri: cedar glade—Continued						
Oak-hickory forest	Stems	28:50	0.0094	1.45	<0.01–0.04	Erdman and others (1976b).
Oak-hickory-pine forest	do	34:49	.01	1.42	<.01–0.02	Do.
Unglaciated prairie	do	39:49	.013	1.67	<.01–0.04	Do.
Pennsylvania: Armstrong and Indiana Counties	Leaves	9:9	.13	1.37	.08–0.20	H.A. Tourtelot (unpub. data, 1979).
American green alder (*Alnus crispa*):						
Alaska	Stems or stems and leaves	8:10	.016	2.53	<.01–0.15	Gough and others (1991).
Usibelli Coal Mine	Stems and leaves	6:6	.01	--	.01–0.01	Gough and Severson (1981b).
Sitka alder (*Alnus crispa* subsp. *sinuata*):						
Alaska	Stems or stems and leaves	2:5	--	--	<.01–0.04	Gough and others (1991).
Thinleaf alder (*Alnus incana*):						
Alaska	Stems	2:3	.011	1.71	<.01–0.02	Do.
Shrub birch (*Betula glandulosa*):						
Alaska	Stems or stems and leaves	7:9	.015	1.97	<.01–0.04	Do.
Dwarf arctic birch (*Betula nana*):						
Alaska	do	9:9	.019	1.77	.01–0.05	Do.
Paper birch (*Betula papyrifera*):						
Alaska	Stems	3:3	.054	1.70	.04–0.10	Do.
Dogwood (*Cornus florida*):						
Pennsylvania: Armstrong and Indiana Counties	Leaves	79:79	.28	1.46	.10–0.55	H.A. Tourtelot (unpub. data, 1979).
Do	Twigs	9:9	.11	1.50	.06–0.20	Do.
Beech (*Fagus grandifolia*):						
Pennsylvania: Allegheny County	Wood	8:12	.0094	2.43	<.005–0.04	Do.
White oak (*Quercus alba*):						
Missouri: oak-hickory forest	Stems	48:50	.018	1.43	<.01–0.04	Erdman and others (1976b).
Oak-hickory-pine forest	do	48:49	.019	1.43	<.01–0.04	Do.
Willow oak (*Quercus phellos*):						
Missouri: flood-plain forest	do	45:45	.032	2.02	.01–0.30	Do.
Post oak (*Quercus stellata*):						
Missouri: cedar glade	do	46:49	.020	1.56	<.01–0.04	Do.
Oak (*Quercus* sp.):						
Pennsylvania: Allegheny County	Wood	9:9	.0086	1.36	.005–0.01	H.A. Tourtelot (unpub. data, 1979).

Sweetgum (*Liquidambar styraciflua*):						
Missouri: flood-plain forest	Stems	47:47	.065	2.36	.01–0.40	Erdman and others (1976b).
Shagbark hickory (*Carya ovata*):						
Missouri: oak-hickory forest	do	19:19	.022	1.52	.02–0.04	Do.
Oak-hickory-pine forest	do	7:7	.027	1.45	.02–0.04	Do.
Mesquite (*Prosopis glandulosa*):						
New Mexico: Hidalgo County	Leaves	80:80	.38	1.97	.04–1.2	Raines and others (1985).
Luna County	do	4:4	.23	2.32	.10–0.70	Do.
Texas: Brewster and Presidio Counties	do	6:6	.17	2.81	.06–0.65	Erdman and others (1979).
Ohia (*Metrosideros collina*):						
Hawaii: Hawaii Volcanoes National Park	do	14:14	.053	1.67	.02–0.10	Connor (1979).
Hawaii: Hawaii	do	35:35	.067	2.04	.02–0.25	J.J. Connor (unpub. data, 1979).
Arctic willow (*Salix arctica*):						
Alaska	Stems	2:3	.014	1.83	<.01–0.02	Gough and others (1991).
Diamondleaf willow (*Salix pulchra*):						
Alaska	Stems or stems and leaves	4:6	.015	2.13	<.01–0.04	Do.
Tyonik B–5 quadrangle, Capps Coal Field	Stems	87:90	.088	1.75	<.05–0.30	Gough and Severson (1983).
Usibelli Coal Mine	Stems and leaves	6:6	.013	1.43	.01–0.02	Gough and Severson (1981b).
Feltleaf willow (*Salix alaxensis*):						
Alaska	Stems or stems and leaves	7:7	.038	3.79	.01–0.64	Gough and others (1991).
Littletree willow (*Salix arbusculoides*):						
Alaska	Stems	1:3	--	--	<.01–0.01	Do.
Grayleaf willow (*Salix glauca*):						
Alaska	Stems or stems and leaves	11:12	.025	3.10	<.01–0.25	Do.
Planeleaf willow (*Salix planifolia*):						
Alaska	Stems	2:2	.014	1.63	.01–0.02	Do.
Willow (*Salix* sp.):						
Alaska	Stems or stems and leaves	14:17	.024	3.10	<.01-0.31	Do.

GPO 683-048/20001

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